Submitted by James Parker in partial fulfillment of the requirements
for the degree of Master of Science in Oral Biology.
Accepted on behalf of the Faculty of the Graduate School by the thesis committee:

05 Jun 15
Date

William Gilbert, DDS
Associate Professor
Research Mentor

05 JUN 15
Date

Manuel Pelaez, DMD MS
Associate Professor
Research Director

05 June 15
Date

Stacy Larsen, DMD
Associate Professor
AEGD Program Director

The Author hereby certifies that the use of any copyrighted material in the thesis manuscript entitled:

Primary Stability of Zirconium vs Titanium Implants: An In Vitro Comparison

Is appropriately acknowledged and, beyond brief excerpts, is with the permission of the copyright owner.

CPT James Parker
2-Year AEGD Program, Ft. Bragg
Uniformed Services University
Date: 02/20/2015

Primary Stability of Zirconium vs Titanium Implants: An In Vitro Comparison

By
James Parker, DDS

A Thesis

Submitted in partial fulfillment of the requirements
For the degree of Master of Science in the
Department of Oral Biology
in the Graduate School of
The Uniformed Services University of the Health Sciences

FORT BRAGG, NORTH CAROLINA
2015

Submitted by James Parker in partial fulfillment of the requirements
for the degree of Master of Science in Oral Biology.
Accepted on behalf of the Faculty of the Graduate School by the thesis committee:

Date	William Gilbert, DDS Associate Professor Research Mentor
Date	Manuel Pelaez, DMD MS Associate Professor Research Director
Date	Stacy Larsen, DMD Associate Professor AEGD Program Director

ACKNOWLEDGEMENTS

I would like to thank the 2-year Advanced Education in General Dentistry Program and the Unifomed Services University of Health Sciences for allowing me the opportunity to obtain a Master's Degree in Oral Biology. Dr. William Gilbert thank you for taking the time to mentor me you are a valuable asset to the students and you have made me a stronger and more confident dentist. Dr. Stacy Larsen, as director of the program, I thank you for your support and budgeting that allowed this project to evolve into a very valuable learning experience. Thank you to Dr. Russell Weaver, who served as a mentor and asset in the classroom and through the early stages of my project and Dr. Manuel Pelaez who took over and mentored me through to completion. Thank you to Ram B Jain for helping to process my statistics. Lastly and most importantly, I would like to thank my wife, Ayumi, my son, Brian, and my daughter, Alina. Their love, support and sacrifice were the inspiration to see this project to completion.

The author hereby certifies that the use of any copyrighted material in the thesis manuscript entitled:

Primary Stability of Zirconium vs Titanium Implants:
An In Vitro Comparison

Is appropriately acknowledged and, beyond brief excerpts, is with the permission of the copyright owner.

Student: James Parker DDS
Program: (AEGD-2 yr) - Ft. Bragg, NC
Uniformed Services University
Date: 02/20/2015

Table of Contents

List of figures

List of Tables

LIST OF ABBREVIATIONS

BIC – Bone Implant Contact

ISQ – Implant Stability Quotient

ITQ – Insertion Torque

RTQ – Removal Torque

SLA – Sandblasted Acid Etched

Y-TZP - Yttria-Stabalized Tetragonal Zirconia Polycrystal

ABSTRACT

Objective: To evaluate the primary stability as measured by ITQ and ISQ of Axis Biodental 4.0 zirconia implants and Biomet 3i 4.0 titanium implants, two commercially available implant systems and determine if a correlation exists between their respective ITQ and ISQ.

Materials and Methods: 17 4.0x 11.5 (actual length) Axis Biodental zirconia dental implants and 16 4.0x11.5 Biomet 3i Certain Parallel Walled titanium dental implants were placed into artificial synthetic bone following osteotomy with the AMANNGIRRBACH universal milling device. The insertion torque was then measured at placement by the Removal Torque Machine, and the implant stability quotient was measured by the Osstell ISQ.

Results: 3i titanium implants were found to have a statistically significantly higher insertion torque than Axis Biodental zirconia implants ($p<.0001$). 3i titanium implants had no statistically significant difference in ISQ from Axis Biodental zirconia implants $p<.67$. The average ISQ was 62.7 for 3i titanium implants and 63.5 for Axis biodental zirconia implants. There was no statistical correlation between 3i titanium implant insertion torque and ISQ $p<.40$, or Axis Biodental insertion torque and ISQ $P<.82$.

Conclusion: Within the limits of this in vitro investigation both Biomet 3i titanium and Axis Biodental zirconia implants achieve primary stability adequate for successful osseointegration and immediate loading protocol. Biomet 3i implants achieve

significantly higher ITQ than Axis Biodental implants which could result in higher long term success rates. Long term in vivo research is needed to confirm these findings.

Introduction

Statement of problem

The material of choice for oral endosseous implants has been and still is commercially pure titanium (Andreiotelli, 2009). This material is widely accepted due to its biocompatibility, favorable mechanical properties and well documented beneficial results (Steinermann, 1998). Disadvantages to titanium include its dull grey color and potential for unwelcomed host reactions due to the release of titanium particles and corrosion products over time (Tschernitschek, 2005). Allergy to titanium may be the cause of dental implant failure in some patients. Sicilla found 9 out of 1500 patients displayed positive reaction to titanium allergy tests. 5 positive patients had experienced unexplained implant failure (Sicilia, 2008). Ceramics have been proposed as an alternative to titanium because they offer better esthetics and potentially favorable biocompatibility and material properties.

At present the ceramic material most often used for producing oral implants is yttria-stabilized tetragonal zirconia polycrystal (Y-TZP, zirconia) with or without the addition of a small percentage of alumina (Andreiotelli, 2009). Zirconia is nonconductive, corrosion resistant and no reports of Zirconia allergy or unwanted host reactions could be found. Zirconia implants are white and mimic natural tooth structure. This is of particular importance if the periimplant mucosa is of a thin biotype or recedes

over time. Zirconia implants may be an alternative to titanium given their excellent esthetic potential, chemical stability, and biomechanical properties (Hochscheidt, 2012).

To date there have been few studies assessing zirconia implant stability. Implant stability is considered one of the most important parameters in implant dentistry. It affects the healing and successful osseointegration of implants. Furthermore its importance increases with modern day requirements and trends towards immediate loading treatments. Immediate loading is defined as prosthetic connection in occlusion to an implant within 48 hours of implant placement. Conventional loading is defined as restoration and loading of an implant following a 3-6 month healing period.

Significance

Implant stability (Total Stability) is divided into two stages: primary stability (implant stability during initial placement) and secondary implant stability (implant stability after healing). In general, primary implant stability has been proven to be mechanical in nature whereas secondary implant stability is a result of biologic events (osseointegration) (Simunek, 2012).

Implant primary stability is an essential factor for successful osseointegration especially if immediate loading of implants is to be considered. Primary stability is determined by bone density, the implant design and the surgical technique (Glauser, 2004). Regarding immediate implant loading, primary implant stability seems to be the most important determining factor for immediate implant loading (Gapski, 2003).

Micromovements greater than 100 micrometers can be sufficient to jeopardize healing with direct bone implant contact (Brunski, 1993).

If primary stability is high, it seems the healing process has only little influence on future implant stability (Friberg, 1999). Simunek confirmed this finding when concluding that implants with low primary stability showed a significant increase in stability during healing and implants with high primary stability lost some stability over time (Simunek, 2012). These finding imply that implants with high primary stability may be immediately loaded.

Implant primary stability may be accurately assessed by measuring the implant stability quotient (ISQ), which utilizes resonance frequency analysis (RFA) (Bragger, 2001), and through the measurement of peak insertion torque (ITQ) which has shown a correlation to bone implant contact (BIC) (Liu, 2011). Utilizing an in vitro model, bone quality and surgical technique can be tightly controlled making implant design, the primary variable affecting implant stability. If Zirconia implants can achieve primary stability comparable to commonly used titanium implants it would support their clinical use, particularly in esthetically demanding situations.

Implant Selection

Biomet 3i Internal Connection Certain parallel walled T3 4.0x11.5 and Axis Biodental Hexalobe 4.0x11.5 (actual length) implants were chosen because they are both 4.0x 11.5 length implants with internal connection, parallel walls, relatively simple

thread geometry and significant surface roughness. Axis Biodental implants have a 1.5 mm collar whereas Biomet 3I implants have a 1mm collar therefore all implants were placed to a depth of 10mm to avoid engaging the implant collar. Biomet 3I implants are self-tapping whereas Axis Biodental implants required use of the M tap. These implant systems are relatively similar and present two realistic options for a clinician debating placement of titanium or zirconia implants.

Review of Literature

Zirconia Implant Physical Characteristics

Y-TZP is made of zirconium-dioxide ($ZrO2$) and yttrium oxide ($Y2O3$), a stabilizing oxide which, when sintered, forms a stable tetragonal structure at room temperature. This transformation toughening is ultimately responsible for the material's high strength. Mechanical property degradation of Y-TZP occurs at relatively low temperatures in the presence of water due to spontaneous transformation of the tetragonal phase ~~in~~ to the weaker monoclinic phase (Piconi, 1999). Regarding loading of one piece zirconia implants, there was no statistically significant reduction in fracture strength of zirconia implants after 1.2 million cycles, representing 5 years of service (Kohal R. , 2011). Furthermore, despite reduced fracture resistance at 5 million cycles, representing 20 years of service, the study suggests the implant will withstand clinical occlusal loading for over twenty years.

Primary Stability / Implant Immediate Loading:

Thus far there are no clinical studies directly evaluating the success of immediately loaded zirconia implants. Several studies on immediate loading have been completed on titanium implants.

Cannizzaro reported on a prospective study of 28 patients that compared immediate loading of 46 single implants and 46 matched conventionally loaded implants. All implants were microtextured, self-tapping Centerpulse Spline Twist MTX implants (Centerpulse Dental, Carlsbad, CA) with at least 3.75-mm diameter and 13-mm length. The authors reported a 100% success rate (46 of 46) with the immediately loaded implants and a 97.8% success rate (45 of 46) in the conventionally. (Cannizzaro G. , 2008).

Lorenzoni noted that implants placed with an immediate restoration demonstrated 0.45 mm mesial resorption and 0.75 mm distal crestal resorption at 6 and 12 months, which was less than that observed for a standard 2-stage approach. This study does not provide long term follow up but the general finding of less bone resorption lends to the idea of long term success of immediately loaded titanium implants (Lorenzoni, 2003).

In addition, Hui noted that the esthetic results in their immediately restored sites were superior to those achieved with a staged approach because of gingival architecture preservation (Hui, 2001). This study did not provide data on soft tissue

stability but once again supports the idea of immediately loaded implants as a viable option for immediate and long term esthetics.

A systematic review by Grutter found a 97.1% success rate for immediately restored implants with a mean follow-up of 23.6 months (Grutter, 2009). These studies suggest that immediate provisionalization is well tolerated by titanium implants. Immediate provisionals are generally considered more esthetic than essex type provisional restorations.

Zirconia Secondary Implant Stability: Bone Implant Contact

Bone implant contact (BIC) is a measure of osseointegration and an indicator of osseoconductivity and secondary implant stability. Several animal studies have been completed comparing the bone implant contact of zirconia implants to that of titanium implants. Dubruille compared the BIC of alumina, zirconia and titanium implants placed in dog mandibles at 10 months. The BIC was found to be 68% for alumina, 64% for zirconia and 54% for titanium with no statistical significance (Dubruille, 1999). Kohal compared sandblasted zirconia implants to sandblasted and acid etched titanium implants in monkeys. The mean mineralized BIC after 9 months of healing and 5 months of loading was 72.9% for titanium implants and 67.4% for zirconia implants. There was no statistically significant difference between materials (Kohal R. , 2006).

Depprich placed 24 zirconia and 24 titanium implants into the tibia of minipigs BIC and then evaluated at 1, 4, and 12 weeks. BIC was found to be slightly better for

titanium than zirconia, the results however, were not statistically significant (Depprich, 2008). Stadlinger evaluated zirconia and titanium implants placed into the mandibles of minipigs. Submerged zirconia and titanium implants were both found to have a BIC of 53% (Stadlinger, 2010).

None of the studies on BIC obtained a statistically significant difference between titanium and zirconia implants. While these studies all have relatively small sample sizes making statistically significant results difficult to obtain, the overall conclusion of these studies is that zirconia is biocompatible and achieves good secondary implant stability as measured by bone implant contact.

Zirconia Secondary Implant Stability: Removal Torque

Removal torque is another measure of implant osseointegration and secondary implant stability. Several studies have evaluated zirconia implant removal torque in animals. Gahlert compared the removal torque of sandblasted zirconia implants to machined zirconia implants, and titanium sandblasted acid-etched (SLA) implants in minipigs at 4, 8, and 12 weeks respectively. The titanium implant showed statistically significant higher removal torque than either zirconia implant type after 8 weeks (Gahlert, 2007).

Gahlert later repeated the experiment with hydrofluoric acid etched zirconia implants and titanium (SLA) implants and obtained no statistically significant differences, though the titanium removal torque remained slightly higher at 8 and 12

weeks (Galhert, 2010). Bormann compared titanium SLA implants to acid etched zirconia implants in minipigs at 4, 8, and 12 weeks. The titanium implant was found to have statistically significantly higher removal torque at 8 weeks. However it was ultimately concluded that the biomechanical bone-tissue response of the investigated zirconia implants is not inferior to that of the roughened titanium surface (Bormann, 2011).

Zirconia Implants Human Clinical Experiments:

Though more human trials are needed with long term follow up there have been promising results regarding zirconia implant placement in humans. Oliva evaluated the 5 year success rate of 831 Cararoot zirconia implants placed with three different surface textures. The results revealed a success rate of 92.77% for uncoated implants, 93.57% for coated implants, and 97.6% for acid etched implants. The overall success rate was 95%. When implants were placed in the esthetic zone using more than 35Ncm torque, some implants were immediately restored, but no data regarding the number immediately restored and the subsequent success rate was provided. Also within the Cararoot protocol used for the study it states that immediate loading should be avoided and that immediate provisionalization in the posterior areas should be avoided. The study achieved similar success rates for anteriorly placed implants and posteriorly placed implants (Oliva, 2009).

In another investigation Lambrich followed 234 titanium implants and 127 zirconia implants an average of 21.4 months. The survival rate of the titanium implants

was 98.4% in the maxilla and 97.4% in the mandible. The survival rate for zirconia implants was 84.4% in the maxilla and 98.4% in the mandible (Lambrich, 2008).

Resonance Frequency Analysis

The most reliable noninvasive method to measure implant stability is Resonance Frequency Analasis (RFA) (Gupta, 2011). A magnet on an aluminum metal rod is screwed into the implant. A signal from a device then produces vibrations in perpendicular directions. The highest and lowest values are then displayed simultaniously. Higher resonance frequencies corresponding to higher implant stability. The resonance frequencies are then transformed into implant stability quotients (ISQs) which range from 0 – 100 (Simunek, 2012).

RFA is a reliable and accurate method for early assessment of the osseointegration process.. Al-Nawas Placed 160 implants in 16 beagle dogs and statistically significantly higher ISQ values at placement were seen for successful implants. It was further stated that ISQ values at placement appeared to be more predictive of implant loss than torque measurment. Furthermore, Friberg found RFA to be more sensitive in detecting changes in implant stability than conventional clinical and radiographic examination techniques (Friberg, 1999).

Sennerby suggested an ISQ above 60 to 65 after implant placement indicates a level above which no further increase is expected and when immediate loading would seem possible. A decreasing ISQ or a level below 45 should be looked upon as a

warning sign and measures to increase the primary stability should be taken. An ISQ value below 40 most likely represents a failed implant (Sennerby, 2002).

Insertion Torque

Insertion torque value (ITQ) is a measure of implant stability and has shown correlation to the implant stability quotient (ISQ), bone implant contact (BIC) and ultimately implant survival. Turkyilmaz observed a clinically significant correlation between the ITV and ISQ values taken at the time of placement of 60 branemark implants in 30 elderly patients.The average ITV and ISQ were 38.9Ncm and 73.3 respectively (Turkyilmaz, 2006). Liu noted a statistically significant correlation between ITV and the three dimensional BIC percentage obtained from micro-CT images in an artificial bone study. CT images were used to calculate the BIC for the entire implant surface potentially yeilding a more accurate result than two dimensional histological section which does not represent the entire implant surface. The study concluded that "ITV should be suitable for calculating the implant stability" (Liu, 2011).

Ottoni observed a statistically significant correlation between implant survival and insertion torque in immediately loaded implants. Forty-six implants were placed in 26 patients in a split mouth design, half of the implants were immediatelly loaded with provisional crowns. Provisionals were relieved 1.5mm occlusally and 1mm incisally and were free of contact in centric occlusion and lateral movement. Implants were placed with a minimum insertion torque of 20Ncm. Over a 24 month period the immediately loaded group had 10 failures, 9 of these failures had been placed with an insertion

torque of 20Ncm. It was concluded that immediate loading of single tooth implants should only be considered with an insertion torque greater than 32Ncm (Ottoni, 2005).

Cannizzaro also observed a statistically significant difference in survival of single tooth implants placed at moderate torque (25-35Ncm) versus those placed at high torque (>80Ncm) . According to a split mouth design 50 patients received two non-adjacent implants one at high torque and one at moderate torque. All implants were immediately loaded with non-occluding provisionals, followed by definitive restoration at 6 weeks. Within 6 months 7 implants failed in 7 patients, all placed with moderate torque. This study concluded that it is preferrable to place implants with high insertion torque (>35 Ncm) when loading them immediately (Cannizzaro G. , 2012).

Contrary to the findings noted above Norton concluded that a torque of 25Ncm would seem more than sufficient for immediate implant loading. Sixty-eight immediate implants were placed with less than 25Ncm torque and immediately loaded in 61 patients. Norton achieved a success rate of 95% with a mean follow up of 46 months (Norton, 2011). This study did not include a control population and unlike the previously mentioned studies participants were strongly advised to avoid any direct functional loading of the implant. Given the findings of Cannizzaro and Otonni it is prudent to consider moderate to high insertion torque essential to the survival of immediatelly loaded implants.

Purpose

The purpose of this study is to compare the primary stability of two commercially available implant systems. Axis Biodental 4.0 mm zirconia implants and Biomet 3i 4.0mm titanium implants, via ISQ and ITQ analyses in an artificial bone model.

Hypothesis

1: There will be no difference in the insertion torque of 4.0 Axis Biodental zirconia implants and Biomet 3i titanium dental implants.

2: There will be no difference in the ISQ of 4.0 Axis Biodental zirconia implants and 4.0 Biomet 3i titanium dental implants.

3: There will be no correlation between Biomet 3i implant ISQ and ITQ.

4: There will be no correlation between Axis Biodental implant ISQ and ITQ

Specific Aims

1: Compare the insertion torque of Axis Biodental zirconia implants and Biomet 3i titanium implants.

2: Compare the (ISQ) implant stability quotient of Axis Biodental zirconia implants and Biomet 3i titanium implants and compare.

3: Determine if there is any correlation between the ITQ and ISQ values of both Axis Biodental and Biomet 3i dental implants.

Materials and Methods

Overview

Seventeen 4.0x 11.5 (actual length) Axis Biodental zirconia dental implants and sixteen 4.0x11.5 Biomet 3i Certain Parallel Walled titanium dental implants were placed into artificial synthetic bone following osteotomy with the AMANNGIRRBACH universal milling device. The insertion torque was measured at placement by the Removal Torque Machine, and the implant stability quotient was measured by the Osstell ISQ. The goal is then to compare and evaluate the measurements as they relate to primary Implant Stability.

Artificial Bone made of solid ridged polyurethane foam was used as an alternative test medium for human cancellous bone. This product does not replicate the mechanical properties of human bone, but it does provide a consistent and uniform material with properties in the range of human cancellous bone.

All osteotomies for implant placement were completed using the AF350 press machine by AMANNGIRRBACH. The AF350 features a playless, double-jointed and smooth arm combined with a ball thread and solid vertical column. This stable milling device enhances accuracy of vertical drillings. Osteotomies for 4.0x11.5 Biomet 3I implants were developed to a Biomet 3I 3.25mm twist drill as recommended by the manufacturer. Osteotomies for the Axis Biodental implants were taken to the 3.4mm Axis Biodental drill M followed by the Axis Biodental 4.0 Tap M as per manufactures instructions. The Tap M was inserted to 5mm the minimal depth facilitating implant placement. All osteotomies were taken to a depth of 11mm allowing a 1.5 mm supra crestal placement of all implants.

Implants were placed at .08 rotations per second with the Imteknik Removal Torque Machine utilizing the RID software. Axis Implants were placed using the Axis Hexalobe holder, Biomet 3I implants were placed using the Biomet 3I Certain implant driver. During implant placement insertion torque was constantly recorded as a function of time. Upon completion of implant placement peak insertion torque was recorded. During implant placement there was fracture of one zirconia implant. Data from this implant was subsequently not included for data analysis.

Following implant placement Axis zirconia implants were fitted with a Type 38 smart peg and Biomet 3I titanium implants were fitted with a type 15 smart peg, as recommended by Osstell. The Osstell RFA was then preformed and the ISQ was recorded from two positions, one parallel to the axis of the polyurethane block termed buccal, and one perpendicular to the axis of the polyurethane block termed mesial.

Statistical Methods

Specific aim 1: The student t test was chosen to test for the null hypothesis, that there is no difference between the insertion torque of 3I titanium and Axis Biodental zirconia implants.

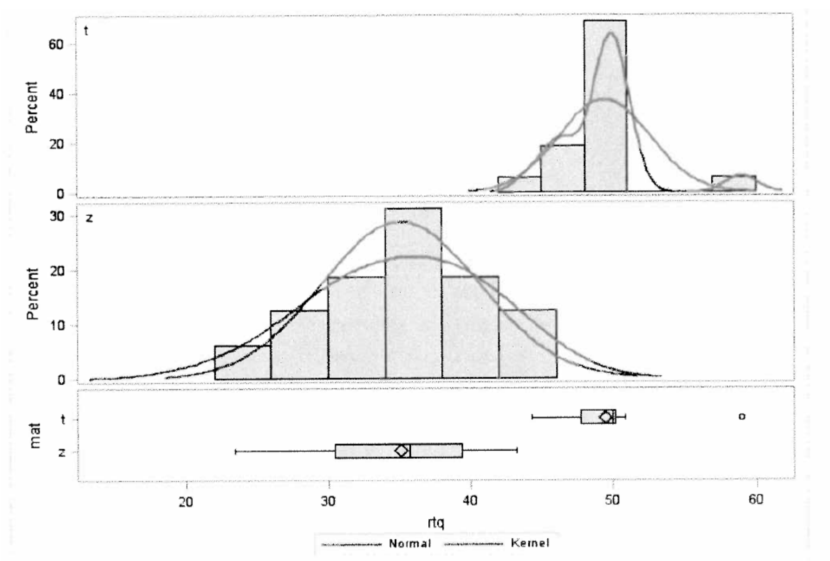
Specific aim 2: The student t test was chosen to test for the null hypothesis, that there is no difference between the ISQ of 3I titanium and Axis Biodental zirconia implants.

Specific aim 3: Pearson correlation coefficients, three nonparametric measures of association, and the probabilities associated with these statistics were calculated to test for any correlation between insertion torque and ISQ.

Results

3I titanium implants were found to have a statistically significantly higher insertion torque than Axis Biodental zirconia implants p<.0001, thus the null hypothysis was rejected. The average insertion torque was 49.4 Ncm for 3I titanium implants and 35.1 Ncm for Axis biodental zirconia implants. The distribution of the data is shown in figure 10. Raw data can be found in Table 1

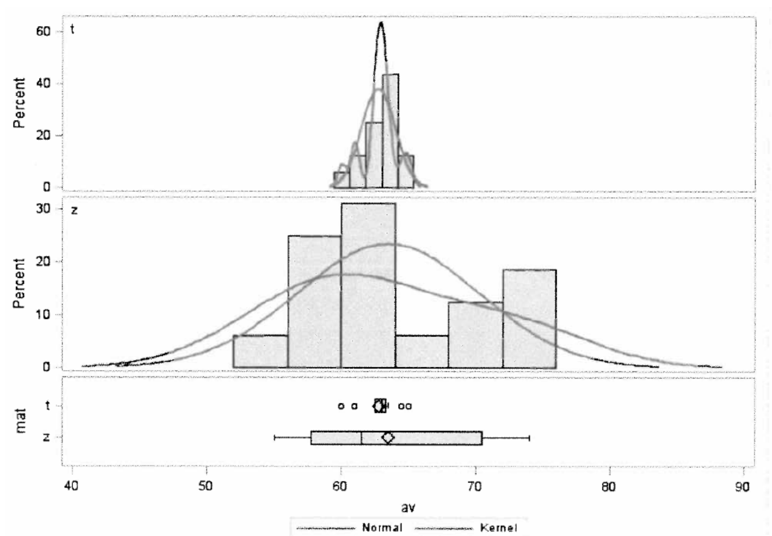
Figure 1: Distribution of ITQ for Biomet 3I implants (top) and Axis Biodental implants (bottom)



Buccal and mesial ISQ values were averaged to form RFA average, the average ISQ for a given implant. These values were then compared via t test. 3I titanium implants had no statistically significant difference from Axis Biodental zirconia implants p<.67, thus the null hypothysis was accepted. The average ISQ was 62.7 for 3I titanium

implants and 63.5 for Axis biodental zirconia implants. The distribution of the data is shown in figure 11. Raw data can be found in table 1.

Figure 2: Distribution of ISQ for Biomet 3I implants (top) and Axis Biodental implants (bottom)



There was no statistical correlation between 3I titanium implant insertion torque and ISQ p<.40, or Axis Biodental insertion torque and ISQ P<.82.

One Axis Biodental implant was fractured during placement and not included in the data.

Figure 3: Image depicting fractured Axis Biodental implant

Discussion

Many authors agree that primary stability is important for implant success and longevity (Cannizzaro G. , 2012). This study was conducted to evaluate the primary stability as measured by ITQ and ISQ of Axis Biodental 4.0 zirconia implants and Biomet 3i 4.0 titanium implants, two commercially available implant systems and determine if a correlation exists between the ITQ and ISQ.

3i Biomet implants were observed to have a statistically significantly higher insertion torque when compared to Axis Biodental implants. Axis Biodental implants were placed with an average insertion torque of 35.1 Ncm and Biomet with an average of 49.4 Ncm. Investigators have suggested approximately 30Ncm to 35Ncm of insertion torque should be achieved for improved prognosis, particularly when the implants are to be immediately loaded (Ottoni, 2005). Axis Biodental zirconia implants meet this threshold on average while 3i Biodental implants greatly exceed this value. The extent of clinical significance to insertion torque beyond 35Ncm remains debatable, but many author state that higher torque is preferred (Cannizzaro, 2012). Ottoni suggests a 20% decreased risk of failure per 9.8 Ncm added (Ottoni, 2005).

No difference in ISQ was observed between the two implant systems. Axis implants averaged an ISQ of 63.5 and 3i implants an average of 62.7. These values exceed 60, the recommendation for immediate loading of implants (Sennerby, 2002). The near identical ISQ values may be due to placement within a uniform medium.

Friberg suggested ISQ may be best understood as an analysis of marginal bone density. This particular measure of stability may be relatively independent of implant system. No correlation was observed between the ITQ and the ISQ of implants placed in this study. This is not surprising as Friberg also failed to find a correlation between ISQ and ITQ at placement within the apical third of the implant site. Friberg did however find a correlation between ISQ and average ITQ values within the crestal third of implant placement (Friberg, 1999).

Why do Biomet 3i implants have higher insertion torque than Axis Biodental implants? In the opinion of this author the difference in torque values may be primarily attributed to implant geometry which is ultimately limited by material properties. Commercially pure titanium has significantly higher fracture toughness than zirconia. Fracture toughness is the ability of a material containing a crack to resist fracture. Zirconia must therefore be smooth to prevent crack formation and may not be able to have cutting threads similar to that of titanium. Self-tapping vs non self-tapping systems may be a confounding factor however Divac studied the primary stability of hybrid self-tapping and non self-tapping implants in vitro at varying residual bone thickness. This study observed no differences in stability quotents between self-tapping and non self-tapping at different simulated bone thickness (Divac, 2013).

Can Axis Biodental implants be immediately loaded? Within the limits of this in vitro investigation Axis Biodental zirconia implants on average exceed recommend ITQ and ISQ for immediate loading and successful osseointergration. Long term in vivo

studies are needed to confirm these findings. Practitioners would be wise to take a cautious approach with respect to immediate loading.

An area of concern is any potential for fracture of zirconia implants. Given the nature of the fracture with in this study the fractured implant could have been easily retrieved at the time of surgery with no long term detriment to the patient. In vivo research and documentation is needed to adequately assess this potential complication. At present one piece zirconia systems may mitigate the risk for fracture. One piece systems have the prosthetic abutment and implant in one piece increasing thickness and avoiding a thin zirconia collar. Axis Biodental also offers one piece zirconia implants.

Conclusions

Within the limits of this in vitro investigation both Biomet 3i titanium and Axis Biodental zirconia implants achieve primary stability adequate for successful osseointegration and immediate loading protocol. Biomet 3i implants achieve significantly higher ITQ than Axis Biodental implants which could result in higher long term success rates. Long term in vivo research is needed to confirm these findings.

Appendix

Figure 4: AF350 precision milling device manufactured by AMANN GIRRBACH. Used to ensure uniform angulation of osteotomies

Figure 5: Removal torque measuring device developed and manufactured by IM-Teknik Development AB. Used to place implants with continuous measurement of insertion torque.

Figure 6: Osstell ISQ, Implant stability meter manufactured by Osstell

Figure 7: 30 pound per cubic foot solid rigid polyurethane blocks used to substitute human cancellous bone

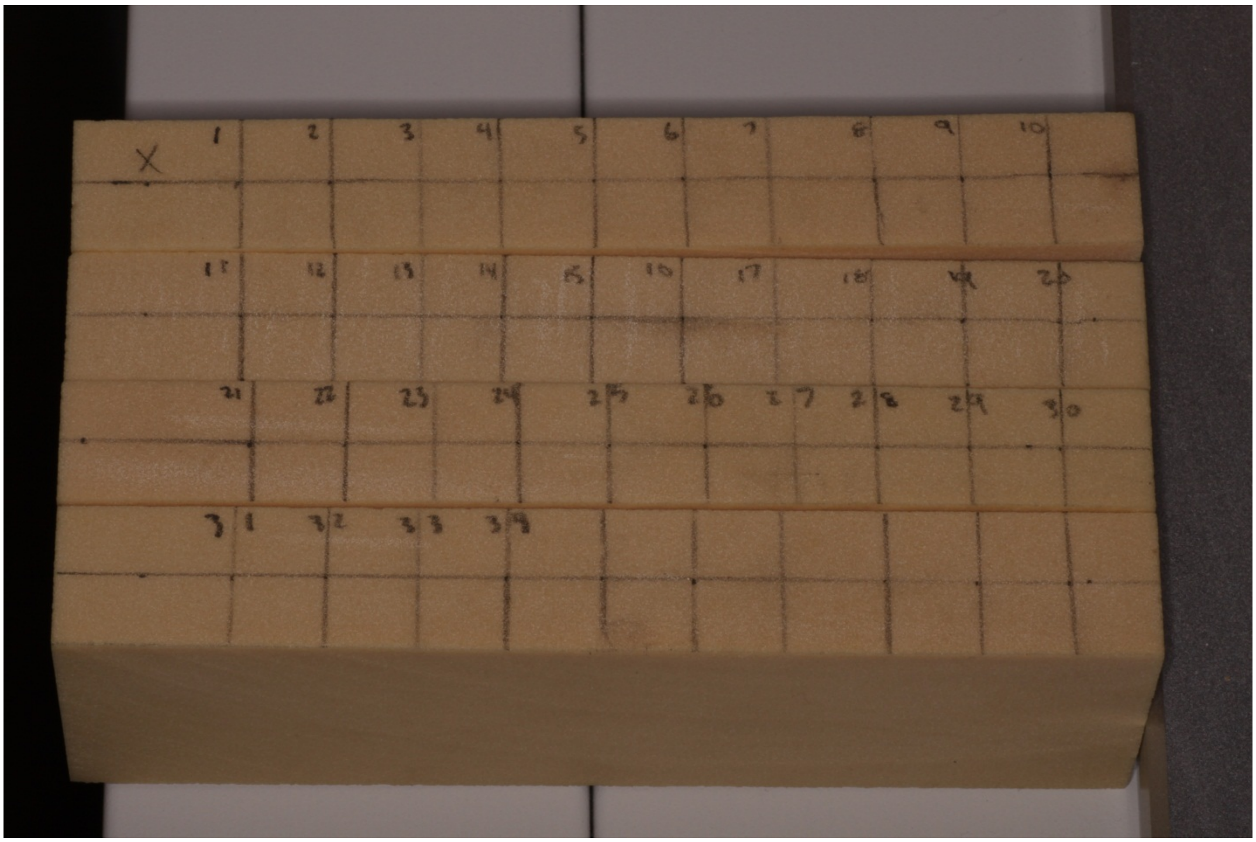


Figure 8: Image depicting osteotomy initiation using the AF350 precision milling device

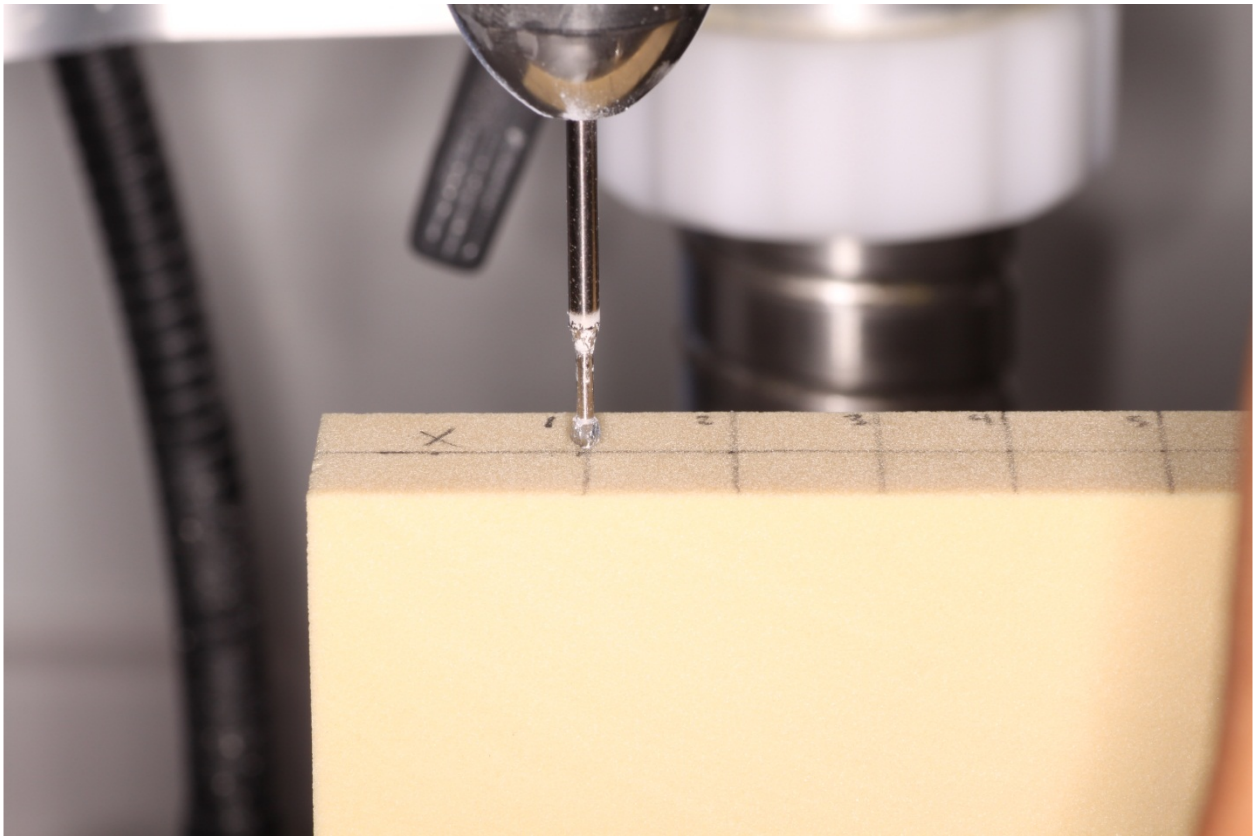


Figure 9: Image of final drills prior to implant placement. Axis Biodental (Left) 3.4mm Drill M and 4.0mm M Tap. Biomet 3I (Right) 2.7mm twist drill and 3.2mm twist drill

Figure 10: Implant placement with IM-Teknik removal torque machine

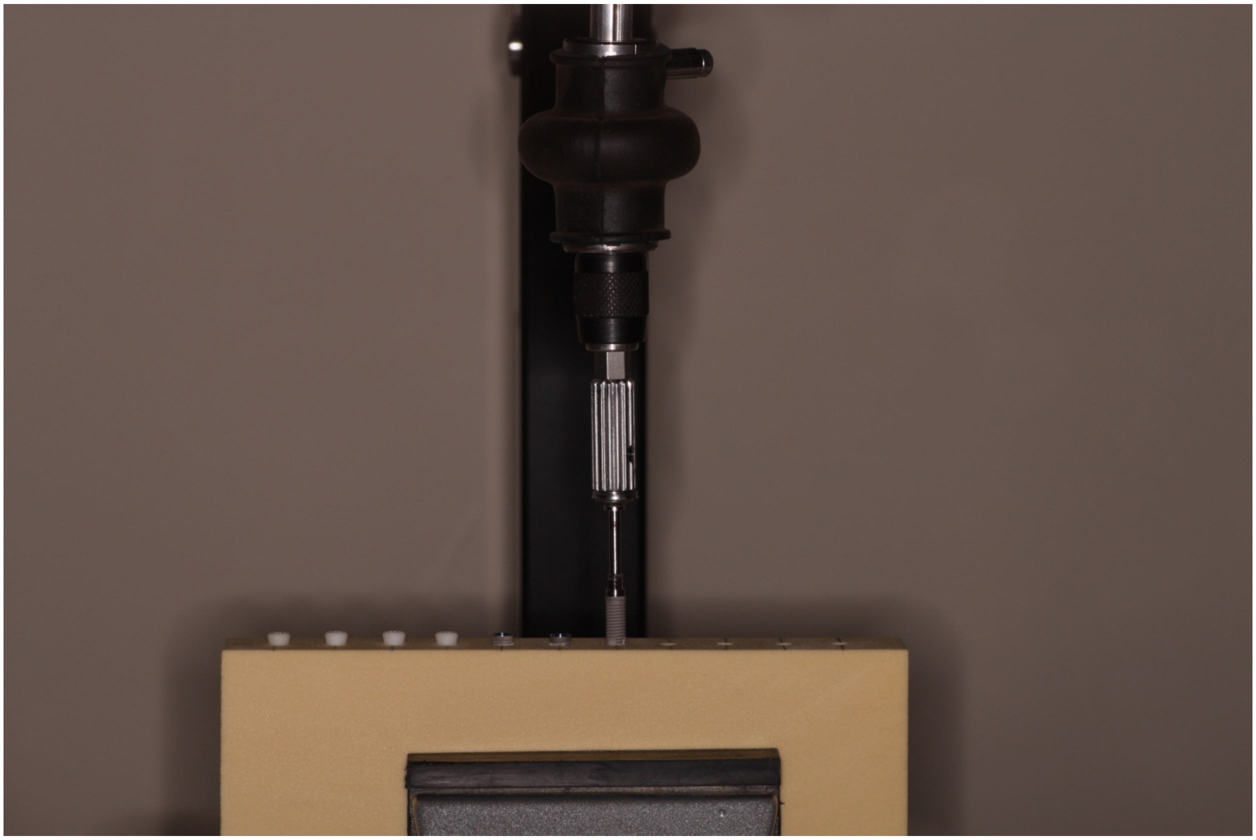


Figure 11: Screen image depicting the torque development during placement of a Bioment 3I implant

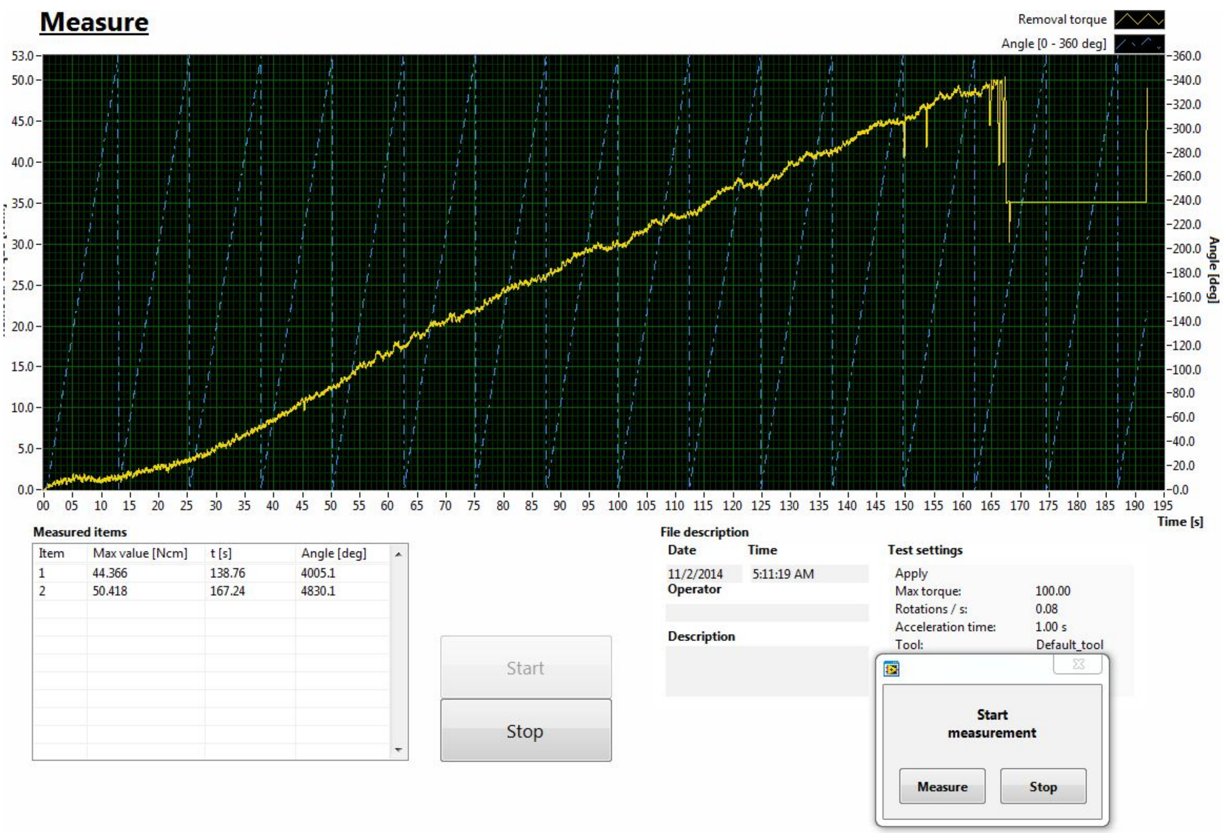


Figure 12: Screen image depicting the torque development during placement of an Axis Biodental implant

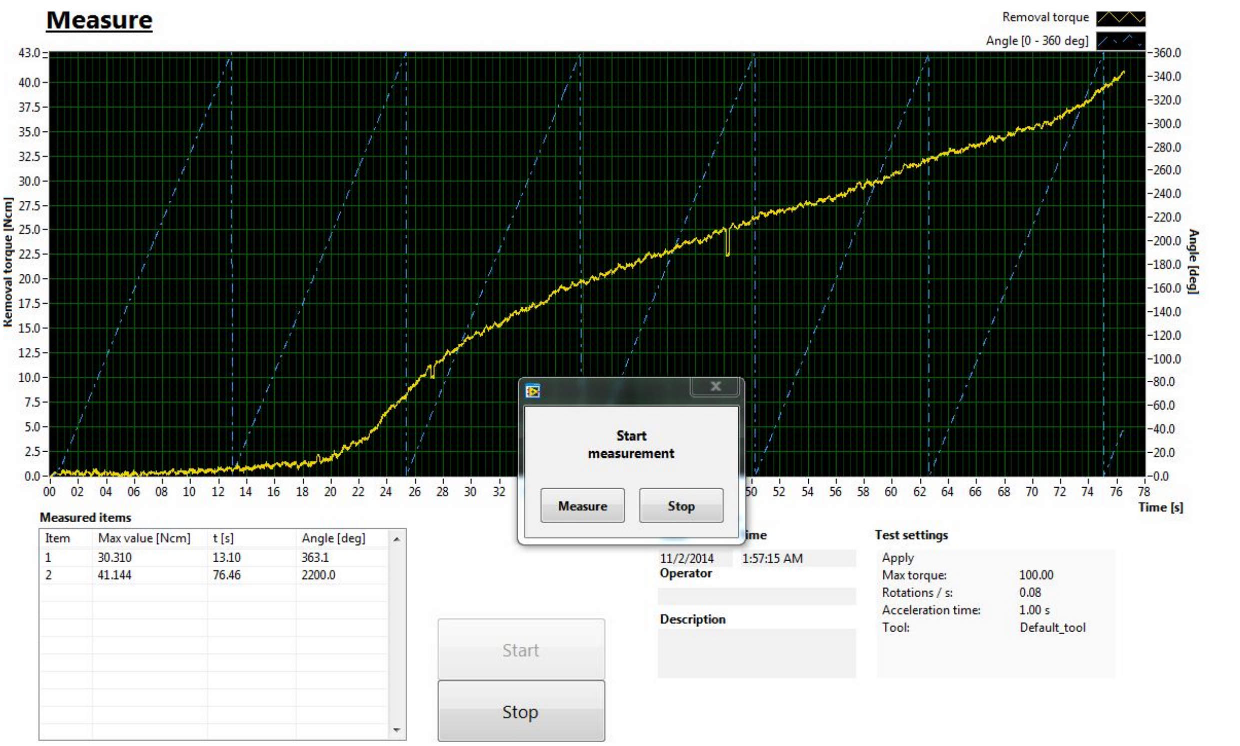


Table 1: Raw Data for 4x11.5 Zirconia implant and 4x11.5 Titanium implant placed in artificial bone (polyurethane foam) at .08 rotations /sec			
Zirconia 4x11.5	ITQ	RFA M	RFA B
Z1	36.5	66	56
Z2	23.4	62	56
Z3	40.4	52	61
Z4	36.7	58	64
Z5	32.1	71	57
Z6	41.1	75	72
Z7	30.0	75	72
Z8	30.8	75	73
Z9	38.4	52	58
Z10	43.2	62	62
Z11	29.8	67	53
Z12	29.2	49	63
Z13	34.9	52	61
Z14	42.5	69	70
Z15	34.8	70	73
Z16	37.5	59	66
Titanium 4x11.5			
T1	46.7	65	62
T2	48.8	64	61
T3	46.1	64	62
T4	50.8	64	62
T5	50.1	63	63
T6	48.6	64	62
T7	50.0	63	62
T8	44.3	63	62
T9	50.4	65	62
T10	49.4	64	61
T11	46.1	64	62
T12	59.0	66	63
T13	50.1	58	64
T14	50.2	67	63
T15	50.0	64	56
T16	50.0	62	60

Works Cited

Amilcar, C. (2011). The effect of implant design on insertion torque and immediate micromotion. *Clinical oral implants research*, 113-118.

Andreiotelli, M. (2009). Are ceramic implants a viable alternative to titanium implants? A systematic literature review. *Clinical oral implant restoration*, 32-47.

Bormann, K. (2011). Biomechanical evaluation of a microstructured zirconia implant by a removal torque comparison with a standard Ti-SLA implant. *Clinical oral implants research*.

Brose, M. (1988). Eight years analysis of alumina dental root implants in human subjects. *Journal of Oral Implantology*, 9-22.

Brunski, J. (1993). Avoid pitfalls of overloading and micromotion of intraosseous implants. *Dental implantology update*, 77-81.

Cannizzaro, G. (2008). Immediate versus early loading of 7-mm-long flapless-placed single implants: a split-mouth randomised controlled clinical trial. *European journal of oral implantology*, 277-292.

Cannizzaro, G. (2012). Imediate loading of single implants inserted flapless with medium or high insertion torque: a 6-month follow-up of a split-mouth randomised controlled trial. *European journal of oral implantology*, 333-342.

Cehreil, S. (2012). Primary stability of histomorphic bone-implant contact of self-drilling and self-tapping orthodontic microimplants. *American journal of orthodontics and dentofacial orthopedics*, 187-195.

De Wijs, F. (1996). Front tooth replacement with Tubingen (Frialit) implants. *Journal of oral rehabilitations*, 11-26.

Depprich, R. (2008). Osseointegration of zirconia implants compared with titanium: an in vivo study. *Head and face medicine*.

Divac, M. (2013). Influence of residual bone thickness on primary stability of hybrid self-tapping and cylindric non-self-tapping implants in vitro. *International journal of oral and maxillofacial implants* , 84-88.

Dubruille, J. (1999). Evaluation of combinations of titanium, zirconia, and alumina implants with 2 bone fillers in the dog. *The International Journal of Oral & Maxillofacial Implants*, 271-277.

Friberg, B. (1999). Stability measurements of one-stage Branemark implants during healing in mandibles. *International journal of oral maxillofacial surgery*, 266-272.

Fuh, L.-J. (2013). Biomechanical investigation of thread designs and interface conditions of zirconia and titanium dental implants with bone: Three-dimensional numeric analysis. *International journal of oral maxillofacial implants*, 64-71.

Fuster-Torres, M. (2011). Relationships between bone denstiy values from cone beam computed tomography, maximum insertion torque, and resonance frequency analysis at implant placement: A pilot study. *The international journal of oral and maxillofacial implants*, 1051-1057.

Gahlert, M. (2007). Biomechanical and histomorphometric comparison between zirconia implants with varying surface textures and a titanium implant in the maxilla of miniature pigs. *Clinical oral implants research*, 662-668.

Galhert, M. (2010). In vivo performance of zirconia and titanium implants: a histomorphometric study of mini pig maxillae. *Clinical oral implant research*, 281-286.

Gapski, R. (2003). Critical review of immediate implant. *Clinical oral implant research*.

Glauser, R. (2004). Resonance frequency analysis of implants subjected to immediate or early functional occlusal loading. *Clinical oral implant research*, 15, 428-434.

Grutter, L. (2009). Implant loading protocals for the partially edentulous esthetic zone. *International journal of oral maxillofacial implants*, 169-179.

Gupta, R. (2011). Resonance frequency analysis. *Indian journal of dental research*, 567-573.

Hochscheidt, C. (2012). Zirconia dental implants: an alternative for today or for the future? *Dental press implantology*, 114-124.

Huang, H. (2003). Early detection of implant healing process using resonance frequency analysis. *Clinical oral implant research*, 437-443.

Hui, E. (2001). Immediate provisional for single tooth implants: An 18 month clinical pilot follow up study. *Clinical implant dentistry related research*, 79-86.

Kahraman, S. (2009). Clinical study on the insertion torque and wireless resonance frequency analysis in the assessment of torque capicity and stability of self-tapping dental implants. *Journal of oral rehabilitation*, 755-761.

Kohal, R. (2006). Zirconiaimplant-supported all-ceramic crowns withstand long-term load: a pilot investigation. *Clinical oral implant research*, 565-571.

Kohal, R. (2011). The effects of cyclic loading and preparation on the frracture strength of zirconium-dioxide implants: an in vitro investigation. *Clinical oral implant research*, 808-814.

Lambrich, M. (2008). Vergleich der U¨berlebensrate von Zirkondioxid- und Titanimplantaten. *Zeitschrift fu¨r Zahna¨rztliche Implantologie*, 182-191.

Liu, C. (2011). Relation between insertion torque and bone-implant contact percentage: An artificial bone study. *Clinical Oral Invest*, 1679-1684.

Lorenzoni, M. (2003). Immediate loading of single-tooth implants in the anterior maxilla. Preliminare results after one year. *Clinical oral implant research*, 180-187.

Markovic, A. (2013). Evaluation of primary stability of self-tapping and non-self-tapping dental implants. A 12-week clinical study. *Clinical implant dentistry and related research*, 341-349.

Menicucci, G. (2012). Comparison of primary stability of straight-walled and tapered implants using an insertion torque device. *International journal of prosthodontics* , 465-471.

Norton, M. (2011). The Influence of Insertion Torque on the Survival of Immediately Placed and Restored Single-Tooth Implants. *The Internation Journal of Oral and Maxillofacial Implants*, 1333-1343.

Oliva, J. (2009). Five-year success rate of 831 consecutively placed zirconia dental implants in humans: A comparison of three different rough surfaces. *The international journal of oral and maxillofacial implants*, 326-344.

Ottoni, J. (2005). Correlation Between Placement Torque and Survival of Single-Tooth Implants. *The International Journal of Oral and Maxillofacial Implants*, 769-776.

Piconi, C. (1999). Zirconia as a biomaterial. *Biomaterials*, 1-25.

Rabel, A. (2007). Clinical study on the primary stability of two dental implant systems with resonance frequency analysis. *Clinical oral investigations*, 257-265.

Sennerby, l. (2002). Resonance frequency analysis current knowledge and clinical implications. *osteointegrazione e carico immediato*, 1-32.

Sicilia, A. (2008). Titanium allergy in dental implant patients: A clinical study of 1500 consecutive patients. *Clinical Oral Implant Research*, 823-835.

Simunek, A. (2012). Development of implant stability during early healing of immediately loaded implants. *The international journal of oral and maxillofacial implants*, 619-627.

Stadlinger, B. (2010). Comparison of zirconia and titanium implants after a short healing period. A pilot study in minipigs. *International journal of oral maxillofacial surgery*, 585-592.

Steflik, D. (1995). Prospective investigation of the single crystal sapphire endosteal dental implant in humans. *Journal of oral implantology*, 8-18.

Steinermann, S. (1998). Titanium—the material of choice? *Periodontal 2000*, 7-21.

Tschernitschek, H. (2005). Nonalloyed titanium as a bioinert metal- A review. *Quimtessence international*.

Turkyilmaz. (2006). A comparison between insertion torque and resonance frequency in the assessment of torque capacity and primary stability of branemark system implants. *Journal of Oral Rehabilitation*, 754-759.

Weingart, D. (1994). Titanium deposition in regional lymph nodes after insertion of titanium screw implants in maxillofacial region. *The international journal of oral and maxillofacial surgery*, 450-452.

Whang, C. (2011). An in vitro investigation of peak insertion torque values of six commercially avalable mini-implants. *European journal of orthodontics*, 660-666.